Deuteron photodisintegration with polarized lasers

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A model independent theoretical analysis of recent experimental data on deuteron photodisintegration with polarized laser beams is presented. We find that it is important to distinguish between the three isovector E1 amplitudes $E1_v^j$ in reaction channels with total angular momentum $j = 0, 1, 2$ and that the isoscalar M1 amplitude $M1_s$is non-zero in the photon energy range $3.5 MeV < E_\gamma < 10 MeV$

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Experimental studies [1] have been carried out during the last decade at the Duke Free Electron Laser Laboratory on photodisintegration of deuterons using 100% linearly polarized laser beams from HIGS, in view of the importance of incisive knowledge on $d + \gamma \rightleftharpoons n + p$ at the astrophysically relevant range of energies, to sharpen [2] the predictions of the big bang nucleosynthesis (BBN) and also of stellar evolution.

The study of $d + \gamma \rightleftharpoons n + p$ has a long history going back by seven decades to the earliest experimental[3] and theoretical[4] studies. Traditionally radiative thermal neutron capture has been identified with an isovector $M1_v$ transition, while deuteron photodisintegration has been attributed to an isovector $E1_v$ transition. The 10% discrepancy noted early in the total cross section between theory and experiment prompted Breit and Rustgi [5] to propose a polarized-target-beam test to detect a possible isoscalar $M1_s$ transition, but Riska and Brown [6] explained this with surprising accuracy as due to meson exchange currents (MEC). Model calculations taking MEC, isobar current and pair current contributions revealed [7] that the dominant $M1_v$ transition strength at thermal neutron energies decreases substantially with increasing neutron energy E_n, while the $E1$ transition picks up the strength in the energy region $10^2 < E_n < 10^3$ keV and becomes dominant

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TABLE I: All the allowed multipole amplitudes

Continuum eigen state	Notation used for the Multipoles
$^1S_0, I = 1$	$M1_v$
$^3S_1, I = 0$	$M1_s, E2_s$
$^1P_1, I = 0$	$E1_s^{j=0}, M2_s$
$^3P_0, I = 1$	$E1_v^{j=0}$
$^3P_1, I = 1$	$E1_v^{j=1}, M2_v$
$^3P_2, I = 1$	$E1_v^{j=2}, M2_v, E3_v$

in photodisintegration. This general scenario [7] is also substantiated by effective field theoretical calculations[10]. Questions with regard to the less dominant amplitudes have however been raised, using different versions of effective field theory [8] and also using the six quark dressed bag model [9]. We may recall that model calculations have lead to traditional forms referred to as Rustgi parametrization[11] and Partovi parametrization [12] for the differential cross section. Equivalently the cross section may also be expanded empirically in terms of associated Legendre polynomials. For example, the Rustgi parametrization is of the form

$$\begin{aligned}\frac{d\sigma}{d\Omega} &= a + b\sin^2\theta \pm c\cos\theta \pm d\sin^2\theta\cos\theta \pm e\sin^2\theta\cos^2\theta \\ &\quad + \cos 2\phi[f\sin^2\theta \pm d\sin^2\theta\cos\theta \pm e\sin^2\theta\cos^2\theta] \end{aligned} \tag{1}$$

where the $\pm$ sign refers to the outgoing protons/neutrons in the c.m. frame. The form used by Schreiber et al [1] is

$$\frac{d\sigma}{d\Omega} = \frac{2\pi^2}{6}[a + b\sin^2\theta(1 + \cos 2\phi)] \tag{2}$$

following Weller et al[13]. A simple analysis using conservation laws reveals all the allowed amplitudes as shown in Table I. Our model independent approach[14] for photodisintegration of deuterons using 100% linearly polarized photons leads to the following expression

$$\frac{d\sigma}{d\Omega} = \frac{2\pi^2}{6}[a + b\sin^2\theta(1 + \cos 2\phi) - c\cos\theta], \tag{3}$$

if all the higher order multipoles are neglected. The recent experimental data reported by Sawatzky[1] and Blackston [1] have also been analyzed in terms of associated Legendre polynomials, where the isotropic term has been normalized to 1. The comparison of this

TABLE II: Estimates of c/a from experiment

E_γ MeV	$\frac{c}{a}$
3.5	0.2325 ± 0.0722
4	0.1084 ± 0.0391
6	0.0160 ± 0.0141
10	-0.1413 ± 0.0074
14	-0.056 ± 0.006
16	-0.077 ± 0.006

analysis with eq.(3) reveals that c/a is non-zero and has values shown in Table II. It was shown in [14] for the first time that the $\cos\theta$ term survives, even if we disregard all the higher order multipole amplitudes and that the coefficient c in eq(3) is given by

$$c = 4\sqrt{6}Re[(2E1_v^{j=0} + 3E1_v^{j=1} - 5E1_v^{j=2})M1_s^*]. \tag{4}$$

The empirical values presented in Table II shows at once that

$$M1_s \neq 0 \tag{5}$$

and that $E1_v^j$ for $j = 0, 1, 2$ can not all be equal. This is a significant result.

It might also be mentioned that we have recently studied [15] theoretically the differential cross section for aligned deuterons using linearly polarized laser beam. Further work is in progress to distinguish between the three $E1_v^j$ amplitudes, by employing polarized deuteron targets which are characterized by both tensor as well as vector polarization. Finally we may mention that it is of crucial interest to astrophysics that the interference term c/a between $M1_s$ and $E1_v^j$ amplitudes shows an increasing trend as E_γ decreases i.e., as we approach astrophysically relevant energies.

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